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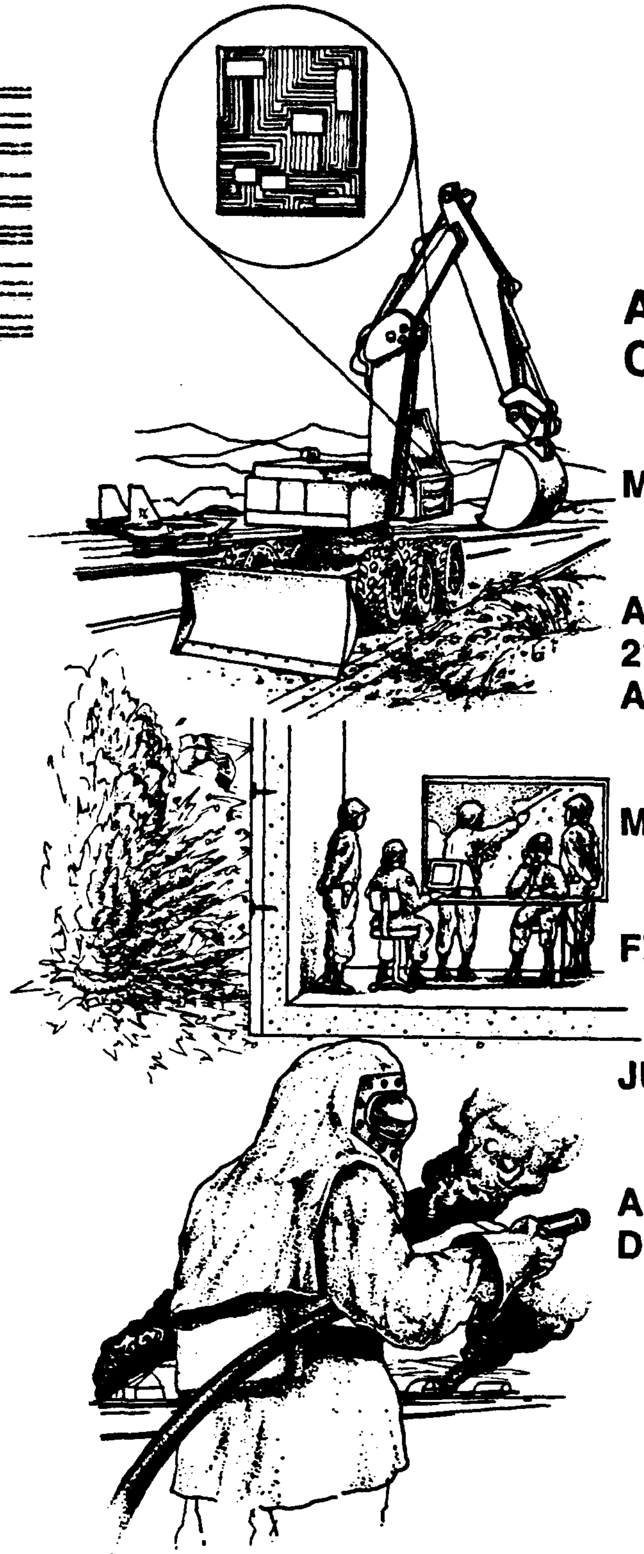

AFCESA GEOTECHNICAL CENTRIFUGE

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The objective of this project was to compile a user's manual for the Air Force Civil Engineering Support Agency geotechnical centrifuge. In the process it was also necessary to upgrade the centrifuge to a state-of-the-art geotechnical research facility. To assist research efforts, a manual was required to provide background information to aid in understanding the AFCESA centrifuge, its support equipment, basic scaling laws that pertain to its use, and guidelines for conducting research involving explosives, soil preparation, and data collection.

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EXECUTIVE SUMMARY

A. OBJECTIVE

The objective of this study was to provide a manual to assist research efforts on the AFCESA Geotechnical Centrifuge. This effort would detail the use of the facility, instrumentation methodology, modeling techniques, and ancillary equipment.

B. BACKGROUND

The use of centrifuges has been under way for several years in the United States. The AFCESA centrifuge was moved to Tyndall Air Force Base in 1986 and research efforts were begun. Serious limitations with gathering data were immediately noted when slip rings were used as an instrument to transfer raw data with low signal amplitude to a computer during testing. The use of explosives had not been fully explored nor had the facility been licensed to use explosives. Each time research efforts were carried out on the centrifuge, weeks or months of preliminary testing were required. Finally, it became evident that learning how to use the centrifuge was becoming part of the problem rather than a tool for solutions.

C. SCOPE

Several research efforts were carried out by universities on the AFCESA centrifuge during the writing of this manual. Many needed modifications to the facility and support equipment became apparent. This manual contains detailed explanations on all modifications and how they affect the centrifuge. A brief discussion on scaling laws is presented, along with technical information to aid the researcher in developing the proper test model.

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PREFACE

This report was prepared by Applied Research Associates Inc. under SETA contract F08635-88-C-0067 for the Engineering and Services Laboratory, Headquarters, Air Force Engineering and Services Center, Tyndall AFB, FL.

This report details the AFCESA Geotechnical Centrifuge Facility located at Tyndall Air Force Base, FL. Work was initiated in July 1990 and completed in September 1992. Mr Paul Sheppard served as the project officer for HQ AFCESA/RACS.

Two individuals are to be acknowledged for their contributions: Dr Teresa Taylor, Associate Professor, Virginia Polytechnic Institute and State University provided advice on almost every design modification made to the AFCESA centrifuge. Ms Kara Olen, GeoSyntec Consultants, has been consulted throughout the writing of the report regarding modeling of soil properties.

This report has been reviewed by the Public Affairs Office and is releasable to the National Technical Information Service (NTIS). At NTIS it will be available to the general public, including foreign nationals.

This technical report has been reviewed and is approved for publication.

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SECTION I

INTRODUCTION

A. OBJECTIVE

The objective of this project was to compile a user's manual for the Air Force Civil Engineering Support Agency geotechnical centrifuge. In the process it was also necessary to upgrade the centrifuge to a state-of-the-art geotechnical research facility. To assist research efforts, a manual was required to provide background information to aid in understanding the AFCESA centrifuge, its support equipment, basic scaling laws that pertain to its use, and guidelines for conducting research involving explosives, soil preparation, and data collection.

B. BACKGROUND

As geotechnical centrifuge research efforts were carried out by AFCESA, learning how to use the centrifuge became so time consuming that the centrifuge became part of the problem rather than a tool for its solution. Several centrifuge studies were initially sponsored by AFCESA. In each case, serious limitations were noted. Dr Y.S. Kim, Catholic University, conducted tests on soil-structure interaction with a 1/60 scale model. Commercial strain gauges and LVDTs were used to measure strains and deformations on the model. Readings were passed through slip rings to a recording instrument. Unfortunately, the signal-to-noise-ratio was poor, and very little data were retrieved. Methods of obtaining uniform soil samples had been painstakingly slow, due to an inefficient pluviation test apparatus. Dr Teresa Taylor, Virginia Polytechnic Institute and State University, found that the original sand-raining device was ineffective. Fifty-pound buckets of sand had to be carried up a vertical ladder to be poured into makeshift containers that could rain sand into a test bucket for later testing. During loading onto the centrifuge, the test buckets frequently were bumped, thereby disturbing the uniformity of the soil. Additionally, Dr Taylor discovered that a study to determine when a centrifuge payload reached a vertical position was needed. The weight of the model within the payload bucket, and the location of its center of gravity, would prevent the model from reaching a vertical position at desired g levels. Explosive testing on the centrifuge had not been approved by the numbered Air Force Safety Office, nor by the local base safety officer. There was no approved procedure for storing explosives, and a study to determine explosive limits within the containment housing had not been performed. Each time explosives were used, a new safety plan was initiated, which took months to coordinate and be approved at Air Force level. During explosive testing, the only visual recording device was a shuttered video camera. High-speed event timing required a different type of photography. This posed serious limitations, since the center pedestal of the centrifuge was taken up by instrumentation.

C. SCOPE/APPROACH

In recent years, acceptance of the geotechnical centrifuge as a research tool has become widespread. Soil is a difficult engineering material, which exhibits nonlinear and anisotropic behavior. The centrifuge is now generally recognized as an acceptable tool for characterizing and replicating soil-structure behavior under a variety of conditions. Only during the last 2 years has a concentrated effort been made to upgrade the AFCESA facility to realize the priorities of the Civil Engineering Laboratory geotechnical centrifuge. These priorities are: (1) civil engineering applications, (2) weapon effects, and (3) soil consolidation and fluid migration. Between 1990 and 1992, several studies were conducted to determine the types of centrifuge support equipment that would most benefit university and industrial research efforts as they pertain to the above Air Force goals. An approach to solve these problems was undertaken and several features were identified: instrumentation, explosive licensing, on-site explosive storage, sample preparation methods, data acquisition system (to replace slip rings), upgraded camera system, characterization study of Tyndall beach sand, and a complete bibliography of centrifuge-related topics to be entered into the AFCESA Technical Information Center database.

SECTION II

THE GEOTECHNICAL CENTRIFUGE FACILITY

A. THE AFCESA CENTRIFUGE FACILITY

The model E-185 centrifuge installed at Tyndall Air Force Base, Florida, was originally built for testing avionic equipment and mechanical devices to be subjected to high g-service loads. Built by GENISCO in 1953 as a medium-size centrifuge, it was installed at Kirtland Air Force Base, New Mexico. In 1986, under the guidance of Dr Paul Thompson and Mr Mike Womack, the centrifuge was moved to Tyndall AFB (Reference 1). A containment vessel (Figure 1) 7 feet high, 17.3 feet in diameter, and with 9-inch thick reinforced concrete walls, was built to conduct research with explosives.

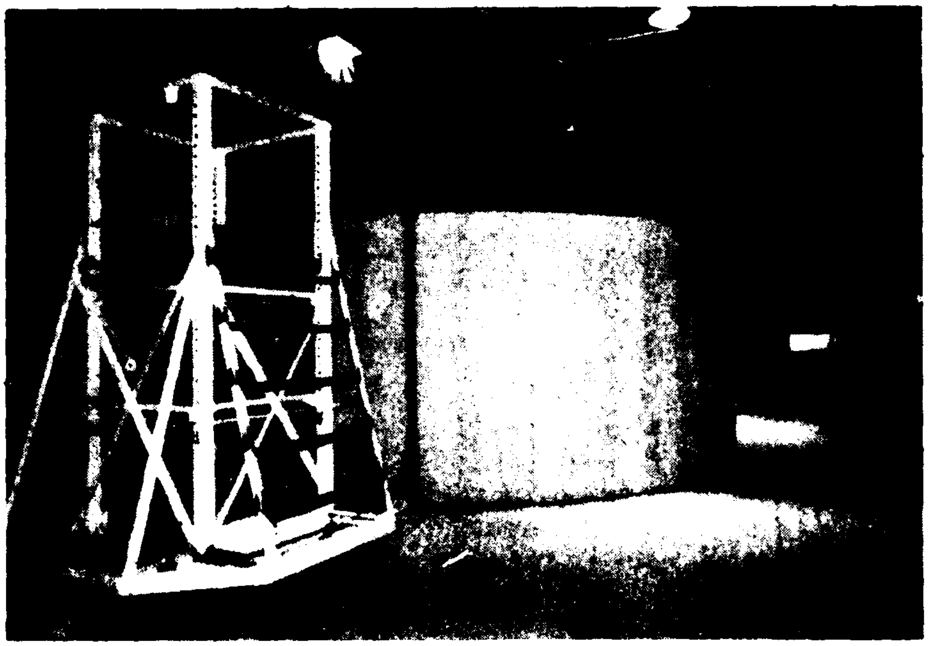


Figure 1. Geotechnical Centrifuge Containment Vessel

B. DESCRIPTION OF THE CENTRIFUGE

The machine can accelerate a 300-pound payload at 100 g maximum. By reducing the acceleration the payload can be raised to a maximum of 500 pounds (Reference 2).

The centrifuge is driven by a hydraulic pump system, consisting of a motor, a variable displacement pump, a constant displacement fluid motor coupled to the rotor driveshaft (Figure 2), and two pressure relief valves. Rotational stability and constant torque are provided by a solenoid operated, spring-loaded four-way control valve. The hydraulic power unit is housed in the control room and a fluid motor is installed at the bottom of the rotor assembly in the containment vessel.

Figure 2. Rotor Assembly

The boom consists of two arms connected to a center pedestal. Each arm is 72 inches long. Mounted on the end of each arm is a 30 inch square cradle, held by aluminum roller bearings that allow the cradle to pivot freely. This permits the model surface to remain perpendicular to the vector sum of the centrifuge acceleration and the acceleration due to gravity. If necessary, the cradle can be locked in position at an angle of 45, 90, 135, or 180 degrees.

Initially, the centrifuge arms are balanced statically by counterbalance weights placed on the arm opposite the payload section. In flight, however, an automatic dynamic balancing motor moves the arms until the center of gravity of the two masses (each arm) is at the axis of rotation. The maximum movement of the two arms is 12 inches, and, if this maximum displacement does not achieve dynamic balance, a warning light in the control room console illuminates to warn the operator.

Both hydraulic and electrical services are available on the centrifuge. Compressed air and fluids can also be fed in via the control console. Primary electric signals for controlling servo motors, lights, cameras, and the explosive firing system are provided via a stacked slip ring. Forty slip rings (channels) are available. Included in these slip rings are 12 channels with shielded cabling for instrumentation. In practice these are rarely used, since an on-board data acquisition system is preferred.

SECTION III

PERFORMANCE AND TEST LIMITATIONS

A. WEIGHT LIMITS

The centrifuge can work with a maximum payload of 300 pounds at 100 g for a force equal to 30,000 pounds. The desired weight can be increased and the g level force lowered accordingly:

30,000 lb / 400 lb @ 75 g

or

30,000 lb / 500 lb @ 60 g

B. PAYLOADS

After the model has been placed or constructed within the bucket (payload), an electrical hoist lifts the bucket into the containment vessel and onto the payload platform (Figure 3).

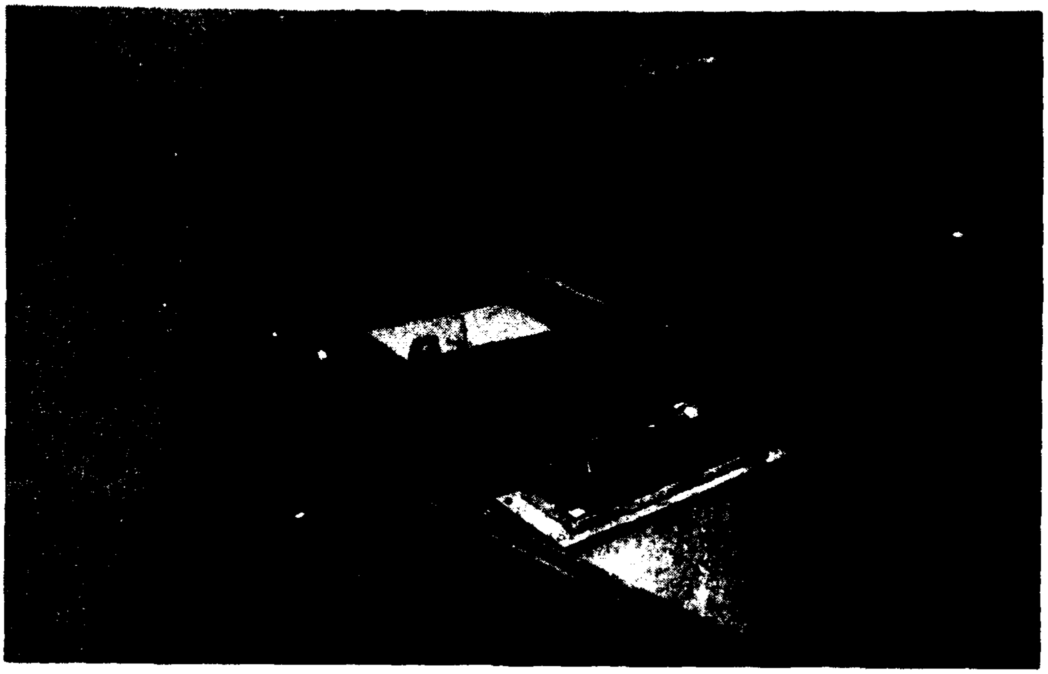


Figure 3. Payload Bucket on Platform

All buckets are positioned on and attached to an aluminum base with four bolts. The position depends on the horizontal weight distribution of the bucket. The maximum allowable dimensions of any bucket are 20 inches long, 20 inches wide, and 20 inches high. Table 1 shows the dimensions of available buckets. All payload buckets can accommodate RP-83 detonators for explosive testing. Additionally, the square bucket (20 x 20 x 18 inches) has a permanently mounted soil interface pressure gauge. This gauge is quite useful for measuring reflective waves due to explosions in a soil medium.

Table 1. PAYLOAD BUCKETS

SHAPE	DIMENSIONS	MATERIAL
Cylindrical	D=18 H=12	1/4" Aluminum
Cylindrical	D=18 H=18	1/4" Aluminum
Cylindrical	D=24 H=7	3/8" Polyvinyl
Square	L=20 W=20 H=12	1/4" Aluminum
Square	L=20 M=20 L=16	3/8" Aluminum

1. Payload Rotation:

When using a payload bucket placed on the swing arm, centrifugal forces cause the swing arm to rotate towards the vertical position (90 degrees). In most tests the desired position is for the payload to be perpendicular to the centrifuge arms; in this way the vector sum of the centripetal force and gravity is the same as the vector force of the model being subjected to gravity.

2. Eccentric Weights:

The height of the payload or physical location of the model inside the bucket can cause an under-rotation, in which the bucket does not achieve the vertical position for the desired g force. When this happens an "eccentric weight" is required. By placing a small weight on the inside of the swing platform (Figure 4), the center of gravity is changed (on the platform), and will assist reaching the vertical position at the desired g loading.

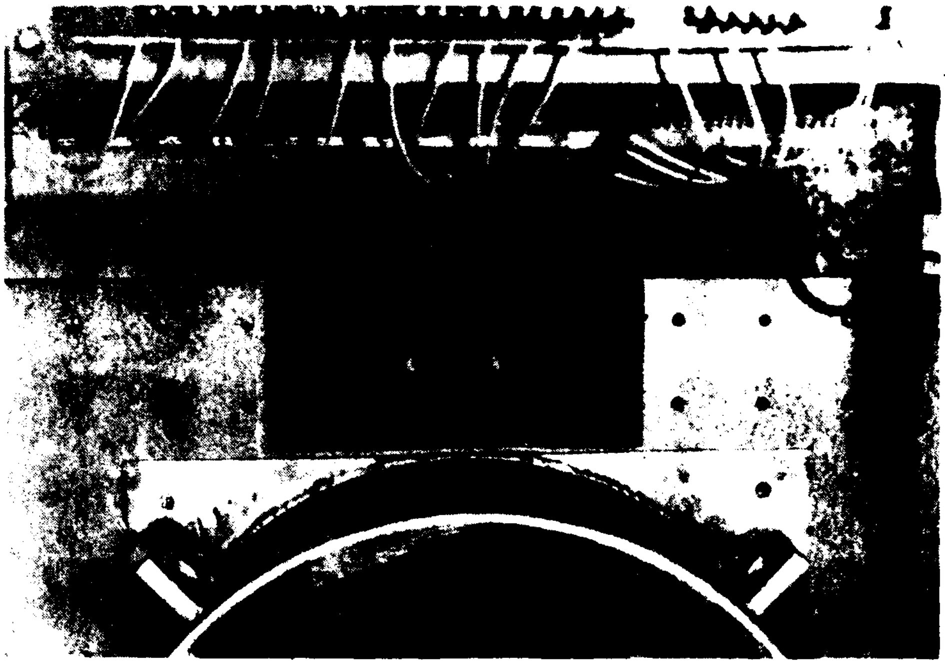


Figure 4. Eccentric Weights on PLatform

The use of eccentric weights depends on the center of mass for the geometric shape being used (square bucket or cylindrical bucket). The author and Dr Taylor performed tests to determine the amount of weight to use. Figure 5 gives the eccentric weights required for a given payload weight and g level in a cylindrical bucket.

3. Vertical Indicator:

As the centripetal acceleration increases, the platform rotates until, at a given acceleration and payload weight, the platform has rotated to the vertical position. Located on the platform is a microswitch that will illuminate a "Vertical" light on the control room console. If eccentric weights are used, it is possible to rotate beyond the vertical; however, this is not recommended. When using explosives it is desired that the platform be in the vertical position ± 2°. This will assure that the force vector of acceleration and explosive charge are perpendicular to the plane of rotation. The maximum explosive weight used on the centrifuge is 5 grams.

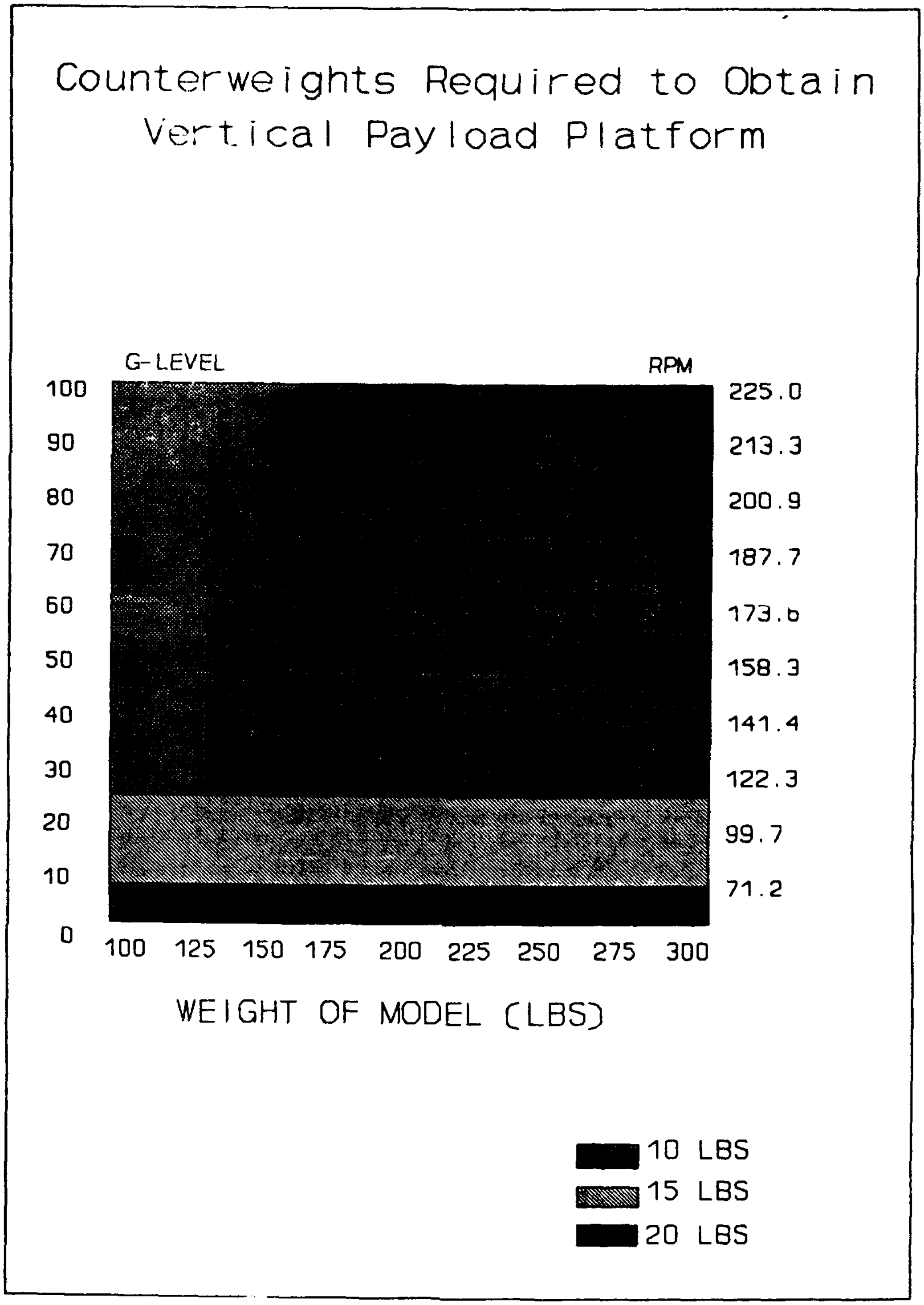


Figure 5. Eccentric Weight Payload

SECTION IV

BASIC SUPPORT EQUIPMENT AND OPERATION

A. GENERAL

The centrifuge facility has top-of-the line support equipment to assist research efforts. This includes a modest soil laboratory, computers (386, 25 MHz with twin 90M Bernoulli drives), equipment to prepare soil samples for centrifuge testing, photographic support equipment, and a complete dark room, machine shop, and carpenter shop. Technicians are available for assistance, including preparing models for centrifugation. This section deals with a portion of the support that is of primary interest to research efforts.

B. PLUVIATION

Preparing most centrifuge models requires the use of soil. Sand is usually the material of choice due to its uniform properties. While clays are used in some studies, sand is more readily prepared for studies of soil reinforcement or buried underground structures, because of its reproducible densities. Additionally, sand is readily available at Tyndall Air Force Base. In order to build a model with sand, there are two basic requirements:

- The soil must be homogeneous; that is the density should be uniform throughout.
- The soil model must be reproducible regardless of the number of times it is built or who prepares it.

C. SOIL PREPARATION

Preparing the soil model requires a soil placement method that will achieve the above requirements. This includes vibration, soil raining, and compaction.

The AFCESA centrifuge laboratory is well equipped for sand raining, more commonly referred to as pluviation.

D. BRIEF HISTORY

The original AFCESA pluviator was designed and constructed by Dr Taylor during her graduate work at Tyndall AFB (Reference 3). In 1990 Mr Frank Dorle was contracted to design a new pluviator that would be stable, capable of handling heavy sand loads, and able to produce different unit weights. In 1991, the pluviator was upgraded (Figure 6) to provide the following:

- A method of causing the sand raining to end abruptly.
- A method to rain soil into both round and square payload containers.
- An electric hoist to lift the payload container onto the centrifuge without causing disturbance to the soil model (Figure 7).

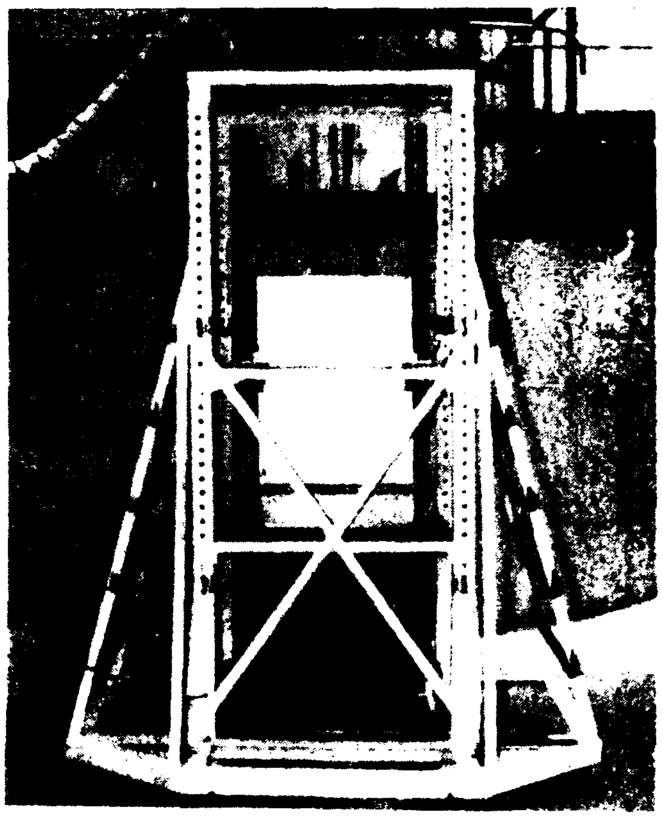


Figure 6. Pluviator

Figure 7. Electric Hoist

E. PRINCIPLE OF OPERATION

The principle of pluviation is shown in Figure 8. As shown, the sand is loaded into the hopper by means of a bucket attached to the hoist. A wooden shutter plate with 1/2-inch staggered holes is aligned with the bottom of the hopper. Under the wooden shutter is a moveable aluminum shutter plate with the same hole pattern. By sliding the aluminum shutter plate, the holes are aligned with those of the wood plate, and sand raining begins. A detailed pluviation checkguide is given in Appendix C.

The sand passes through the two diffuser screens. These screens are typically 1/4-inch wire mesh screens. The top screen is horizontal and planar and the bottom screen is also horizontal and planar, but rotated 45 degrees about a vertical axis with respect to the top screen (Reference 4). The two screens

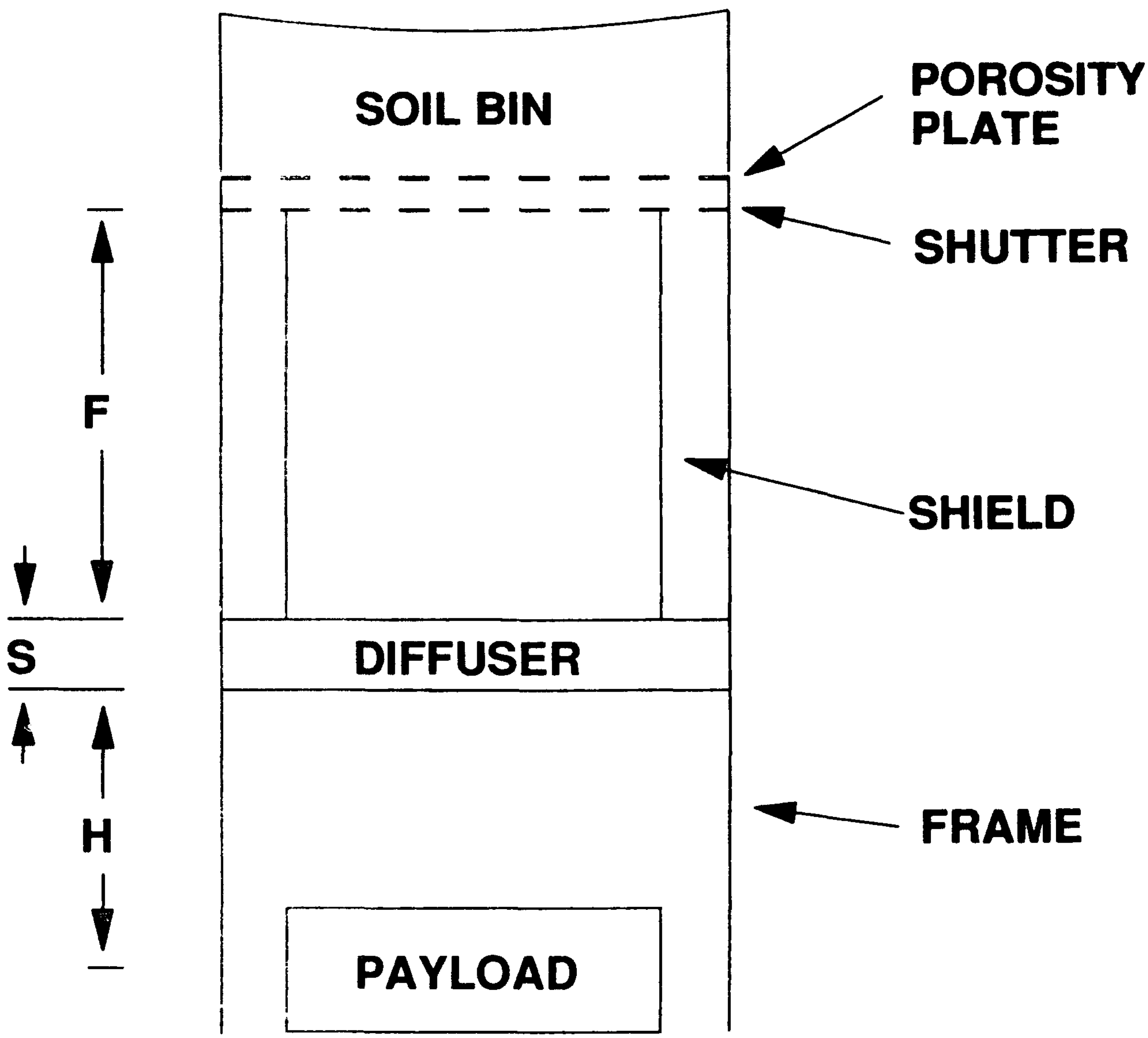


Figure 8. Principle of Pluviation

are 12 inches apart. When the sand passes through the two screens it becomes diffused, thus creating a uniform vertical flow. The sand then continues falling into the payload bucket.

Unit weight of the soil is regulated by adjusting the falling height between the porosity plate and the diffuser screens (reference 5). For instance, a falling height of 36 inches yields a unit weight of 105 lb/ft^3 with Tyndall beach sand; changing the height to 18 inches yields 100 lb/ft^3.

F. USE OF ELECTRIC HOIST

Upon completion of pluviation, the payload bucket is attached to the electric hoist, weighed, and lifted up to the centrifuge. Using the hoist avoids disturbing the payload, thus preserving soil homogeneity.

The hoist vertical motion is controlled by a simple hand device. Horizontal motion is controlled by pulling on a steel cable. The hoist is arranged so that moving the payload from the pluviator to the payload arm requires very little effort.

The maximum hoist lifting capacity is 1000 pounds. A digital readout loadcell is attached to the hoist hook to allow accurate payload weight recordings.

SECTION V

SCALING LAWS

A. GENERAL

Full scale testing is an expensive process. Tests on scaled down models offers an alternative method at greatly reduced costs. The design of a model is governed by laws of replica scaling. Predictions for the prototype response are made and then scaled to predict the response on a model.

B. REPLICA SCALING RELATIONSHIPS

For convenience and economy, the model length equals the prototype length divided by the scale number, n. Mass density and stress are the same for model and prototype. Therefore the following basic relationships apply:

$$l = 1/n$$

$$m / l^3 = 1$$

$$\tau = m/lt^2 = 1$$

From these basic relationships, other scale factors can be derived as shown in Table 2 (Reference 5):

Table 2 Replica Scaling Relationships

QUANTITY	SCALE FACTOR SYMBOL	EXPRESSION	VALUE
length	l	l	$1/n$
mass density	ρ	ml^{-3}	1
stress	τ	$ml^{-1}t^{-2}$	1
mass	m	m	$1/n^3$ (1)
time	t	t	$1/n$ (2)
velocity	v	lt^{-1}	1
acceleration	a	lt^{-2}	n
force	f	mlt^{-2}	$1/n^2$
energy	e	ml^2t^{-2}	$1/n^3$
consolidation coeff	c_v	l^2/t	$1/n$

SECTION VI

INSTRUMENTATION

A. PACIFIC INSTRUMENT RECORDER

An on-board data acquisition system is installed on the AFCESA centrifuge to minimize electrical noise. The low level signal generated by dynamic model response can be lost in the noise of the slip rings when using an external data acquisition system. The on board system, a Pacific Instrument Model 5700 Transient Data Recorder (TDR) (Figure 9), uses filters with programmable steps of 2kHz, 5kHz, 10kHz, 20kHz, 50kHz, and wideband (100kHz). An amplifier with programmable gain in steps of 1, 2, 5, 10, 20, 50, 100, 200, 500, and 1000, is available and can be accessed through applications software. This software provides the operator with a data base of transducer and test parameters, plus integrated control of the signal conditioning amplifiers. Data are scaled and displayed in specified engineering units determined by transducer calibration data contained in the database.

Figure 9. Data Acquisition TDR

Control of the data base is via function keys from a master menu (Reference 7). Program and data storage are accomplished with a Winchester disk or Bernoulli cartridge.

The data acquisition system itself is located on the centrifuge arm. The system is shock-hardened to withstand 50 g along any axis. The TDR has 16 channels. Each channel module consists of a programmable signal conditioner, an amplifier, a filter, and a 12-bit analog- to- digital converter. Also available is an excitation power supply that is programmable from 0 to 12 volt in one volt increments. The digitizer is programmable for both pretrigger and post-trigger memory segments at sample rates between 1 MHz and 10 Hz. Each channel contains 256K of nonvolatile memory, organized in 16 equal segments, and uses a battery backup for a minimum of 40 hours. Each segment is individually programmable for sample rates. Appendix E provides the user with the most commonly used functions for centrifuge testing.

B. RESISTORS

Allen-Bradley industrial grade, 1/8 watt, 1000 ohm carbon composition resistors (Figure 10) (style RC05 with +/- 5% tolerance) were used to measure peak stresses and blast wave velocities.

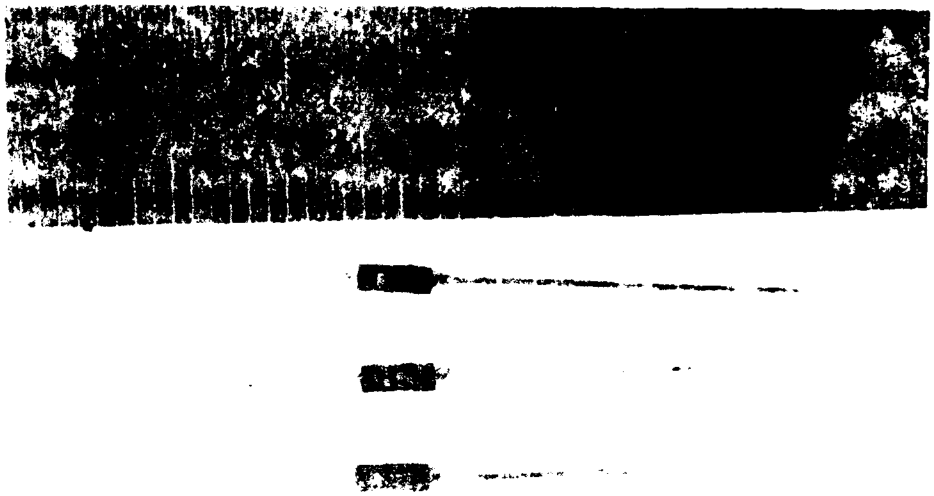


Figure 10 [illegible] Resistors

These resistors are configured as a Wheatstone Bridge with one arm of the bridge acting as a transducer. [illegible] advantage of the fact that carbon changes its resistance [illegible] to the way in which the first micropnones operated) [illegible] and repeatable. Also the price (approximately 16 cents) and small size ([illegible] cm x .16 cm) makes them an excellent choice. Dr Wayne Charlie [illegible] Andy Walsh, Colorado State University, conducted tests at Tyndall AFB in [illegible] using 1/8 watt, 1000 ohm carbon resistors (Reference 7).

1. Test Method:

The test consisted [illegible] 3 inches of Tyndall Beach sand in a 2 inch diameter mold. Densification of the soil was performed with a Proctor hammer. A 1/8-watt carbon resistor was placed in the mold, with its lead wires threaded through an orifice at the side (Figure 11). The resistor was oriented with its long axis [illegible] soil [illegible] was placed over the resistor and compacted with a proctor hammer. The entire mold was weighed, and the soil unit weight was found to be 100.1 lb/ft^3.

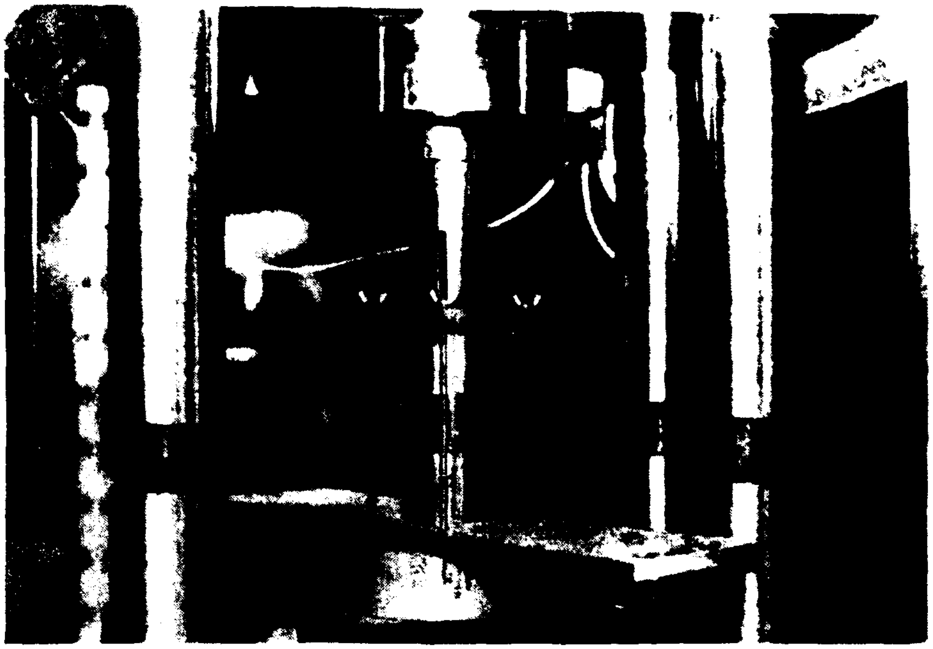


Figure 11. Carbon Resistor Test

The mold was then carried to a Forney load frame. Using a 2 inch steel cylinder resting on top of the soil, plus a load cell, a compression test was performed with a maximum load of 11,000 pounds, which corresponded to an axial compressive stress of:

$$\sigma = \frac{P}{A} = \frac{11,000 lb}{\frac{\pi D^2}{4}} = \frac{11000}{\pi}$$

where D = 2″

2. Software Used:

This stress was recorded using Strawberry Tree data software, and downloaded into Lotus 123 software. The corresponding resistor response was recorded in volts. The load, converted into psi, was also recorded at the same time Therefore a psi vs. volt graph was created (Figure 12).

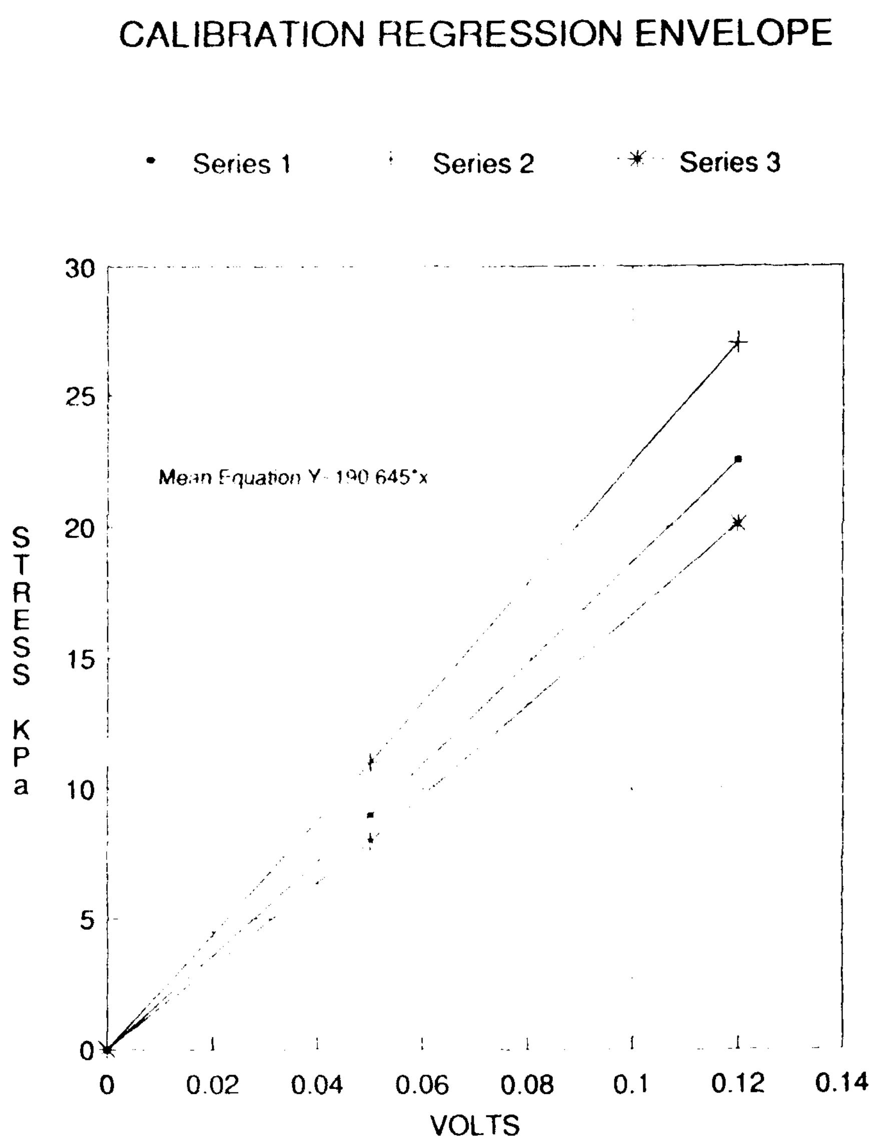


Figure 12. Calibration Curve for Carbon Resistors

C. ACCELEROMETERS

Presently Endevco 7270A piezoresistive accelerometers are being used in soil models in this facility. They are physically small, (0.55 x 0.27 x 0.11 inches), and weigh only .003 lb. Their frequency response is excellent, and they can withstand at least three times their rated value overrange which makes them a good choice if a calculated prediction is not available. This is not to discourage the use of another brand of acclerometer, but these particular gauges have proven very satisfactory on numerous tests with this centrifuge. If other types of gauges are used, size and weight scaling relationships and the present data acquisition system require piezoresistive transducers.

D. PRESSURE GAUGES

The facility is using two different pressure gauges: the Kulite Soil Stress Gauge LQ-080U and Kulite Soil Stress Gauge VM750. The gauges are too large for their intended use but seem to yield correct reflective pressures. Recent tests involving .0068 lb of RDX explosive were conducted with the VM750 gauge. Assuming a 1/30th scale model, the prototype gauge height was (1.5)(30) = 45 inches and the width was (.25) = 7.5 inches. Under load then, the gauge appeared to have the stiffness to give reflective pressure data, rather than free field pressure as originally designed. The pressure reading was 208 psi. Using CONWEP (reference 9) the peak pressure should have been 98 psi. This is indicative of a reflected pressure (Figure 13).

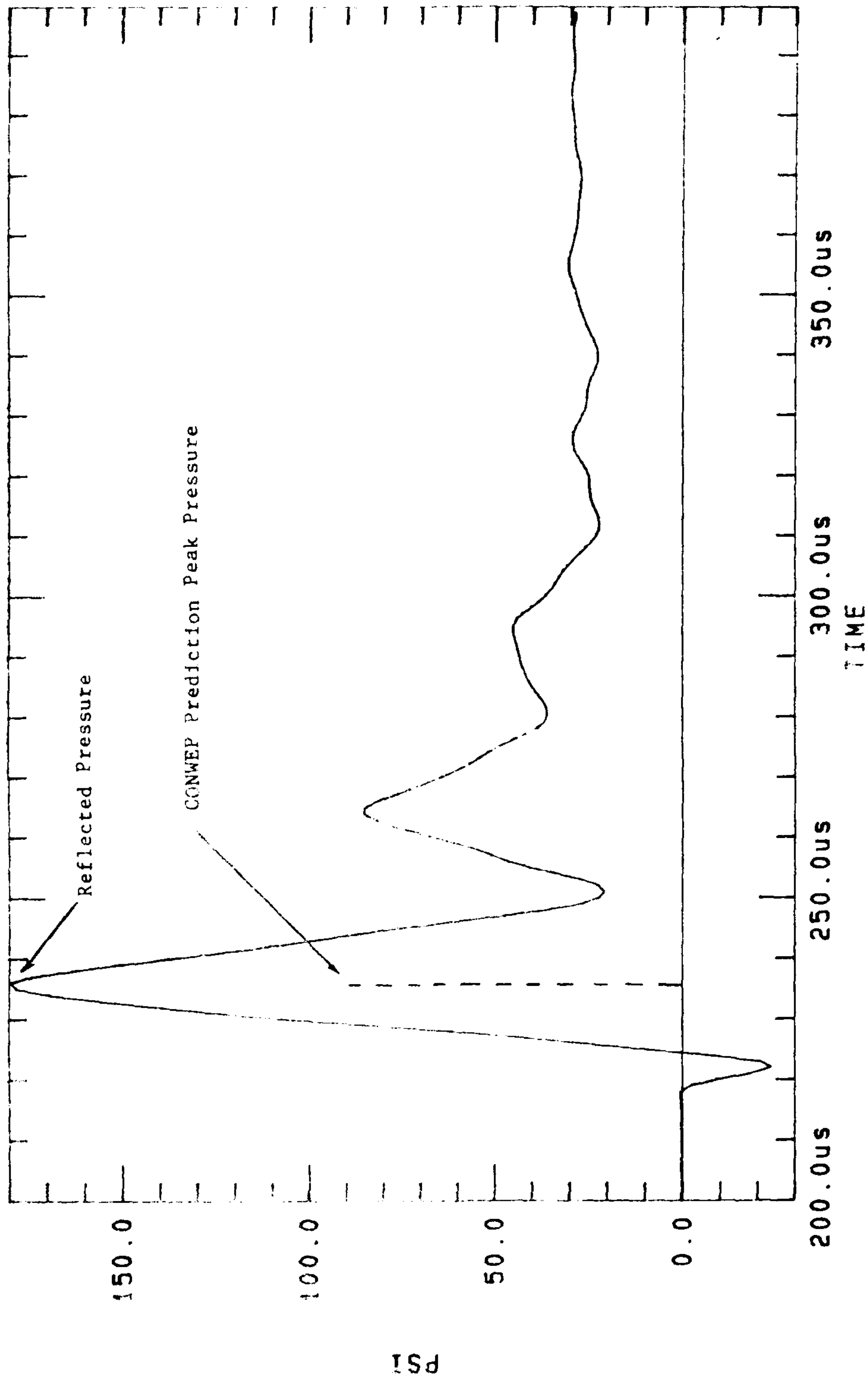


Figure 13. Reflective Pressure From Free-Field Pressure Gauge

E. PHOTOGRAPHIC SUPPORT

A high-speed camera is available for use with the AFCESA centrifuge. The camera is manufactured by Photographic Analysis Inc. It is mounted on top of the centrifuge roof, and records images via a 10-inch parabolic mirror mounted on the centrifuge pedestal (Figure 14).

Figure 14. Center Pedestal with 10-inch Parabolic Mirror

This unique arrangement prevents acceleration stresses from being applied to the camera motor and lens mounting, and possibly causing incorrect speeds from being obtained. The camera control panel is arranged as shown in Figure 15.

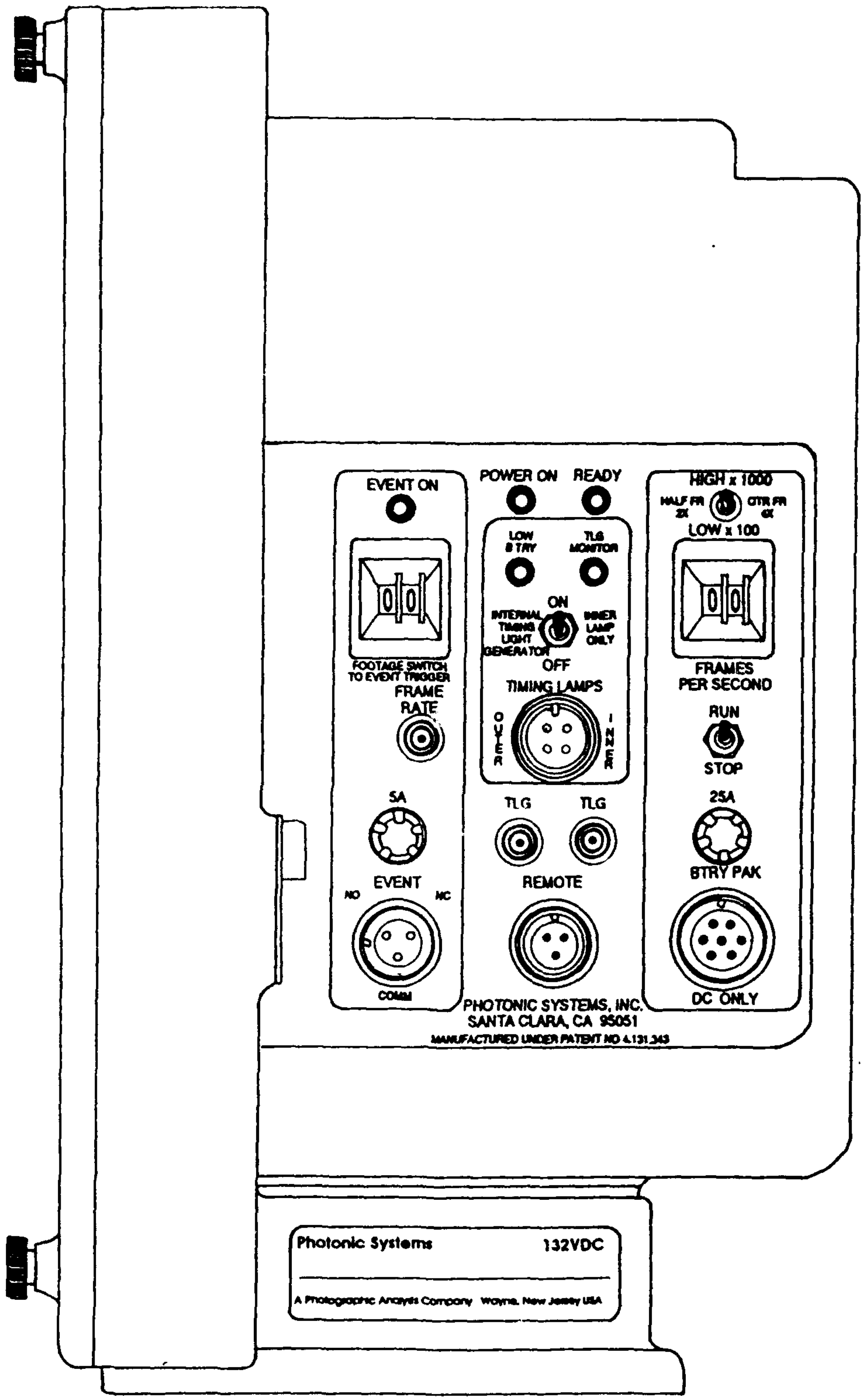


Figure 15. Camera Control Panel

1. Rotating Prism:

The camera uses a rotating prism to transfer images onto 16 mm film. At top speed the camera can record 10,000 pictures per second. The film is video news quality and comes in 450-foot rolls. Camera control is accomplished remotely from the control room. A unique feature of the camera is its ability to reach a desired speed and then trigger an event to be filmed. Timing lights can be registered on the film for later viewing. The lights are recorded on the film at precise intervals, thus allowing accurate analysis of film speed or the event being recorded.

2. Framing Speeds:

The required framing speed depends on the speed of the event, the amount of light available, and the width or length of the field of view within which the event is to take place. The following formula will help determine the distance, object size, and focal length needed for the 16 mm format film:

$$F - \frac{D \times A}{O}$$

where:

A = A_w Aperture Width (10.5 mm)

A_h Aperture Height (7.5 mm)

F = Focal Length of Lens

D = Distance from Lens to Object

O = Object Width or Object Height

EXAMPLE

What lens will be required to photograph an object 20 inches wide and 20 inches high if the camera is positioned 72 inches away as measured from the lens?

$$F = \frac{A_w \times D}{O}$$

and

$$F = \frac{A_h \times D}{O}$$

where: A = A_w Aperture Width (10.5 mm)
A_h Aperture Height (7.5 mm)
D = 1828.8 mm
O = Object Width or Object Height

then:

$$F = \frac{10.5\,mm \times 1828.8\ mm}{508\ mm} = 38\ mm \text{ lens for aperture width}$$

$$F = \frac{7.5\ mm \times 1828.8\ mm}{508\ mm} = 27\ mm \text{ lens for aperture height}$$

Since the 27 mm lens would cover both height and width, this would be lens of choice.

The following formula will help determine the framing rate and exposure time:

$$FRAME\ RATE - \frac{200\ (S)}{BW}$$

where 200 = constant for 16mm film
S = subject's velocity in in/sec
B = shutter ratio (fixed at 2.5)
W = width of field in inches

This calculation would indicate that a width of field of 30 inches and velocity of 12,000 in/sec would require a framing rate of 32,000 pictures/sec. On a 450-foot roll of film this would produce a frozen image. At a normal framing rate of 3000 pictures/sec the camera would capture 30 inches of travel in approximately the first 90 feet of film. The remainder of the film would be of no use.

SECTION VII

OPERATIONS GUIDE

A. SAFETY PRECAUTIONS

The procedures defined in this section will help prevent injury or property damage. All test personnel must know these hazards exist and should try to minimize risks in their centrifuge activities. To prevent being injured by the centrifuge arm while in the containment structure:

- Whoever is in the containment structure must have one of the three interlock switch keys. The centrifuge is wired to require all three keys to start it. This will prevent accidental operation.

- Do not enter the centrifuge containment structure when the red strobe light above the centrifuge is on.

- Leave a door to the centrifuge open when inside the containment structure. Interlock switches on the doors prevent the centrifuge from operating when either door is open.

- Following an operation, check the video monitor to ensure the arms of the centrifuge have come to a complete stop before entering the containment structure. Numbered lines (1-12) mark the inside walls of the centrifuge to determine where the arms have stopped. Numbers 6 and 12 indicate the arms are directly under the doors. If this occurs, the centrifuge must be restarted and the control wheel turned until the arms are located adjacent to any other numbers.

B. OPERATOR RESPONSIBILITIES

Only experienced operators who have had on-the-job training and have been approved by the Chief, Survivability Branch, shall operate the centrifuge.

- Before anyone enters the containment structure the operator must remove the key from Interlock Switch 3 and give it to the person entering the containment structure.

- The operator shall ensure that all persons are out of the pit before the ladder is removed and the doors to the structure closed.

- The operator shall ensure that test items are securely fastened to the centrifuge payload platform and that no loose tools or other items are lying on the centrifuge arms or pit floor before closing the doors.

C. CENTRIFUGE OPERATION

A checkguide is provided in Appendix B, which summarizes the following procedures.

- Ensure that the test items, monitoring equipment, instrumentation, and counterbalance weights have been properly secured to the centrifuge.

- Ensure that no tool, bolt, weight, equipment, or object of any kind is loose inside the containment structure.

- Ensure all persons are out of the containment structure.

- Ensure the static balance of the arms is within tolerance limits (+/- 2 pounds).

- Ensure the payload arms are free to swing by unlocking the two cam locks on each arm.

- Turn the balance motor switch to the "ON" position.

- Exit the containment facility and remove the ladder. Close and secure the latches on the two access doors. This will close both interlock safety switches.

• After checking the video monitor, and looking through the control room window to ensure no person is in or on the containment structure, insert key 3 in the interlock switch on the control panel and turn to the "ON" position.

• Check to see if the red "LIMIT" lamp is off and the green "READY" light is on. If the red limit lamp is still on, turn key 3 to the "OFF" position, remove the key, and check interlock switches on the centrifuge.

• Check the "FORWARD-REVERSE" switch on the control panel. It should be placed in the "FORWARD" position for normal operation.

NOTE

POSITION OF THIS SWITCH SHOULD NEVER BE CHANGED
WHILE THE CENTRIFUGE IS ROTATING

• Ensure the handwheel controlling the hydraulic motor is in the full counterclockwise position. This wil' prevent a hydraulic surge when the motor is started.

• Firmly push the green "START" button.

NOTE

IF RAPID TERMINATION OF THE TEST IS NECESSARY, USH THE RED "STOP" BUTTON TO DECELERATE THE CENTRIFUGE. CONTROL OF THE DECELERATION PROCESS WILL BE AUTOMATIC AND THE CONTROL WHEEL MUST NOT BE USED.

• Turn the handwheel slowly to the right, making sure the pressure indicated on the acceleration pressure gauge does not rise above 1000 psi. When varying the rotor speed, move the handwheel slowly and smoothly to avoid rapid pressure buildup and possible damage to the machine.

• To stop rotation, turn the handwheel slowly to the left until the deceleration pressure gauge begins to register pressure. Do not exceed 1000 psi.

Continue to turn the handwheel slowly to the left until the rpm gauge reads 8 rpm or less. Push the "STOP" button, and observe the video monitor to ensure the centrifuge arm centrifuge has come to a complete stop and is aligned with any number other than 6 or 12.

- Turn all three interlock keys to the "OFF" position and remove key 3.

SECTION VIII

USE OF EXPLOSIVES ON THE AFCESA CENTRIFUGE

A. EXPLOSIVES:

In modeling and simulation an attempt is made to maintain similitude between the model and prototype. The concept for explosives is that a small explosive charge (model) in an acceleration field can simulate the explosive energy and effect of a larger explosive charge (prototype). This discussion will deal with RDX, because it is the primary explosive used in the RP-83 detonator. The heat of detonation of 0.00227 pounds RDX is equal to 0.00258 pounds of TNT (Conversion factor 1.14) (Reference 10). From Table 2, the following relationship is obtained:

$$\frac{W_p}{n^3} = W_m$$

Where W_p = prototype explosive weight, W_m = model explosive weight, and $1/n$ = the geometric scale factor. Calculating this for a hypothetical prototype 500 pounds bomb with 197 pounds of TNT to be modeled at 1/30th scale, the model explosive weight would be 0.007 pounds. If RDX were used as the model explosive then the model explosive weight would be .00636 pounds.

$$\frac{W_m}{1.14} = \frac{0.00726\ lb}{1.14} = 0.00636 lb$$

B. CHOICE OF EXPLOSIVES

Researchers have used explosives in centrifuges for more than 20 years. A review of tests where uniform stress, pressure, and time are important has led to the conclusion that commercially available detonators, such as the Reynolds Industries Systems, Inc RP series detonators (EBW) will provide reliable data. An example is the Reynolds RP-83 (Figure 16).

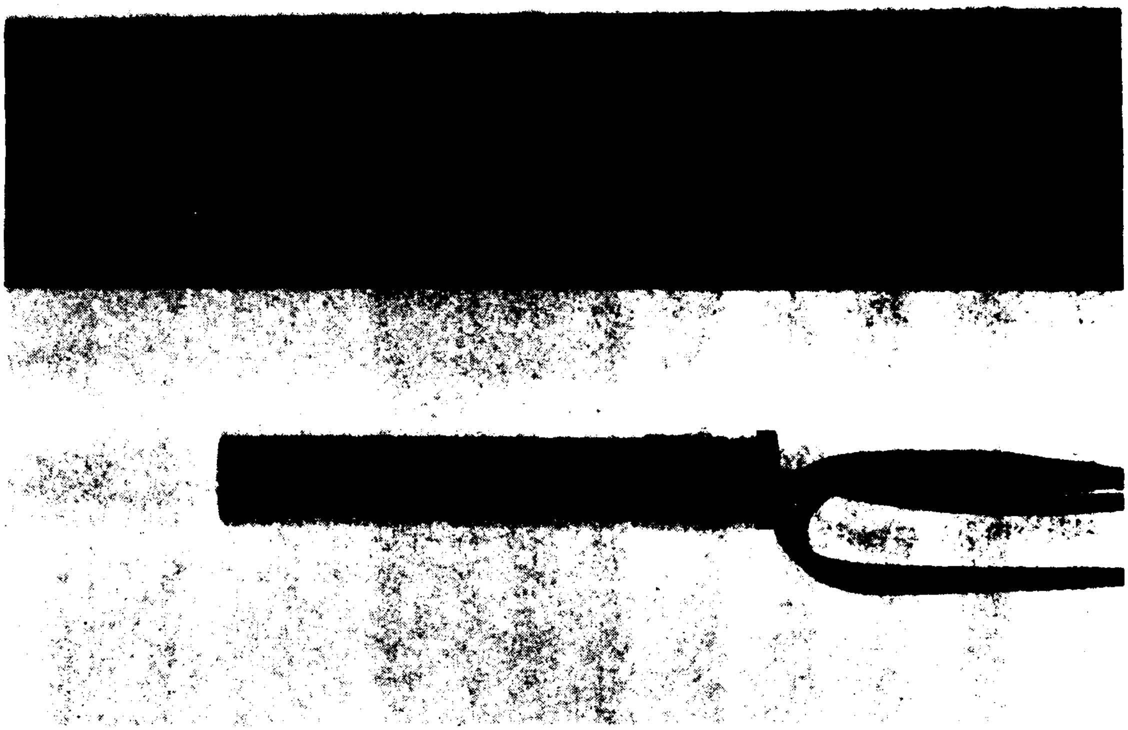


Figure 16. RP-83 Exploding Bridgwire Detonator

This is a standard detonator consisting of an exploding bridgewire, a low-density pressing of pentaerythritol tetranitrate (PETN), a high-density RDX initiator cyclotrimethyelenetrinitramine also called cyclonite (RDX) and a high-density output charge. While similar in construction to a blasting cap, the EBW detonator is characterized by the exclusive use of secondary explosives. It is this feature that accounts for its inherent safety factor, as secondary explosives resist detonation when exposed to heat, friction, fire, static electricity, low voltages, and radio transmissions. Four types of RP detonators are used with centrifuge:

Description	Std.	Mod 1	Mod 2	Mod 3
Weight, lb	0.002	0.0015	0.001	0.0005
Height, in	1.5	1.25	1.0	0.75
Diameter, inch	0.275	0.275	0.275	0.275

C. FIRING SYSTEM

A high-voltage firing system, the Reynolds Industries Model FS-17, has been installed on the AFCESA centrifuge to detonate the RP series detonators. The unit consists of two subassemblies; the control unit and the firing module. The purpose of the control unit is to provide low voltage electrical energy to the firing module and to ensure a safe and reliable EBW detonator firing sequence. Low voltage from the control unit is sent to the firing module which charges a capacitor to 4000 volts. A shorting plug acts as a safety interlock, and when connected to either unit disables the firing circuit.

1. Control Unit:

The control unit is located in the control room and consists of the following (fig 17):

- A shorting plug to preclude arming the firing module.
- A spring loaded switch for arming the firing module.
- A switch for manual triggering.
- An accessory connector for external triggering, such as with a high speed camera.

- A firing voltage meter.
- A battery charger receptacle.
- A battery check meter.
- Fusing to protect the system circuitry.
- A control connector for connecting wires to the firing module.

2. Firing Module:

The firing module is located on the centrifuge pedestal and consists of the following (Fig 18):

- A control connector for connection of wires leading to the control unit.
- An external shorting plug using the same shorting plug as the control unit.
- An output connector (3) for the EBW firing line.

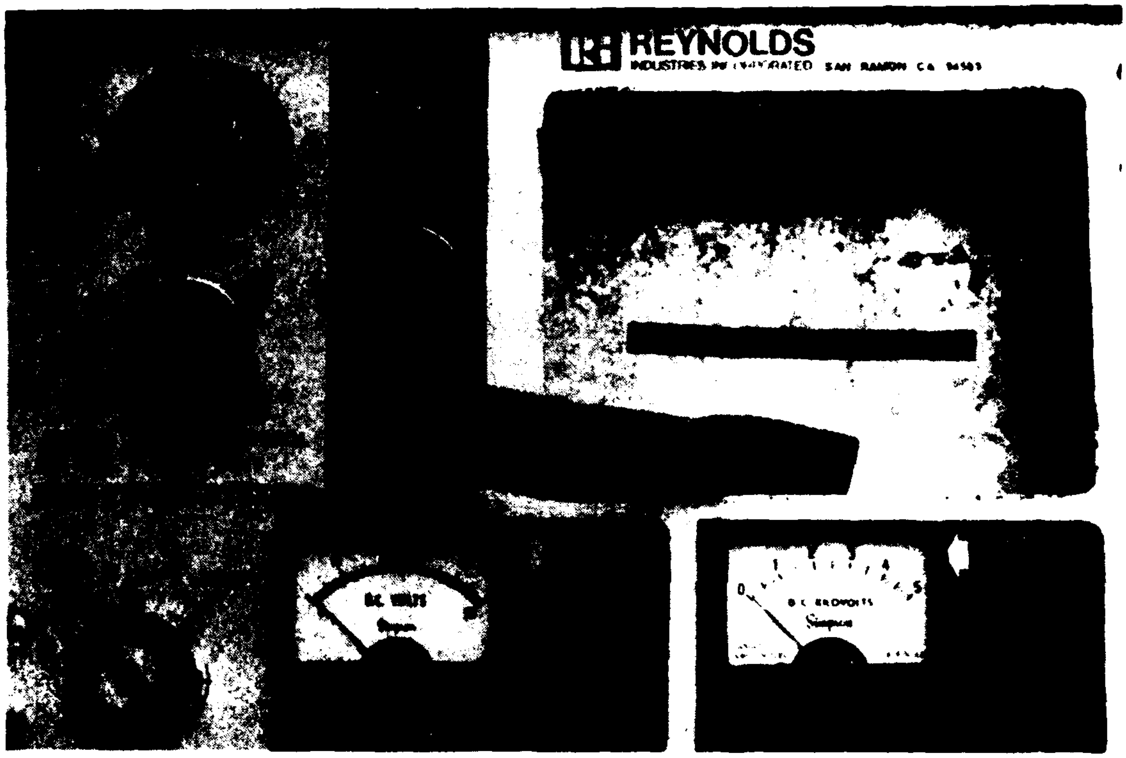
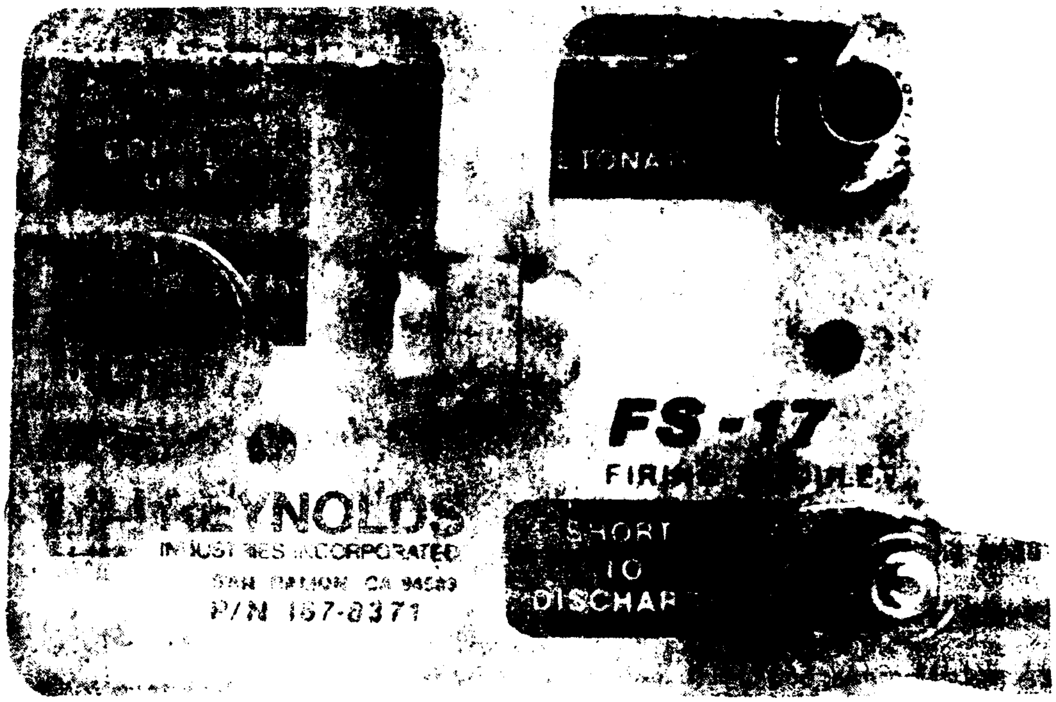


Figure 17. FS-17 Control Module



[illegible] Module

The EBW detonator firing line is shielded to reduce the electrical noise in the 400 [illegible] to the EBW. [illegible] interference with the instrumentation data cables. The wires leading from the control unit [illegible] centrifuge slip rings on their way to the firing module. The [illegible] can be triggered either manually or by being electronically synchronized with the on board data acquisition system depending on test the parameters.

D. EXPLOSIVE SAFETY

The RP series detonators are stored in building 9742 with the centrifuge facility. When used with the centrifuge the maximum net explosive weight will be 0.011 pound.

The following safety precautions must be followed at all times:

- There shall be no smoking in Building 9742.

- Placards shall be placed at the entrances to Building 9742 and the walkways surrounding the centrifuge, to warn personnel that explosive testing is in progress.

- When handling detonators, static producing clothing such as polyester or wool shall not be worn.

- In the event that a detonator misfires the following procedures must be followed:

- The centrifuge operator shall immediately notify safety personnel or the explosive safety officer of the situation.

All personnel shall remain clear of the containment structure.

- No more than one individual shall examine the misfire. While in the containment structure the individual shall have interlock Key 3 and the keys to the FS-17 control module.

- No further testing shall be allowed until the cause of the misfire has been determined.

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APPENDIX A

CENTRIFUGE OPERATION SAFETY CHECKGUIDE

	YES	NO
<u>BEFORE ENTERING CENTRIFUGE</u>		
- Do you have interlock key #3?	___	___
- Is the red strobe light off?	___	___
- Are both doors to the centrifuge open?	___	___
<u>BEFORE STARTING THE CENTRIFUGE</u>		
- Is an approved operator present?	___	___
- Are all test items, instrumentation, and counterbalance weight properly secured?	___	___
- Is the containment structure free of all loose objects?	___	___
- Are all persons out of the containment vessel?	___	___
- Are the doors securely closed?	___	___
- Are all personnel off of the containment structure?	___	___
- Is the centrifuge statically balanced? (Balance motor light "ON")	___	___
<u>DURING CENTRIFUGE OPERATION</u>		
- Is the live video being monitored?	___	___
- Is the hydraulic pressure being monitored (below 1000 psi)?	___	___

APPENDIX B

CENTRIFUGE OPERATIONS CHECKGUIDE

<u>BEFORE STARTING THE CENTRIFUGE</u>

- Ensure all test items are firmly secured to the centrifuge. ____
- Ensure all safety interlocks are operating. ____
- Ensure operation of live video. ____
- Check operation of firing system and data acquisition control (If required). ____

<u>STARTING THE CENTRIFUGE</u>

- Verify blue power light is illuminated. ____
- Turn key in interlock switches 1-3 to "ON". ____
- Check red limit lamp "OFF". ____
- Check green ready lamp "ON" ____
- Place "Forward-Reverse" switch in desired position (Normally in "Forward" position). ____
- Ensure handwheel is turned fully to left to minimize hydraulic surge. ____
- Depress "Green" start button. ____

<u>DURING THE OPERATION</u>

- Turn handwheel clockwise while monitoring hydraulic pressure (not greater than 1000 psi). ____

<u>FOR EXPLOSIVE TEST</u>

- Bring centrifuge up to desired RPM. ____
- Allow RPM to stabilize. ____

- Depress cycling switch for Data Acquisition (cycling takes about 15 seconds). ____

DURING THE OPERATION

FOR EXPLOSIVE TEST

- Start video recorder. ____
- When data acquisition cycle light is illuminated turn arm switch on FS-17 firing system to "Arm" position and hold. ____
- When firing voltage reaches 3500 volts depress firing button. ____
- After detonation release "Arm" switch. ____
- Turn off video recorder. ____

FOR CONSOLIDATION TESTING

- Bring centrifuge up to desired RPM. ____
- Allow RPM to stabilize. ____
- Continue to monitor hydraulic oil temperature for duration of test. ____
- Periodically check and adjust RPM. ____

FOR OPERATIONS CONTROLLED BY HIGH SPEED CAMERA

- Ensure camera cables from back of high speed camera are connected to camera control box on control console. ____
- Bring centrifuge up to desired RPM. ____
- Depress cycling switch for data acquisition (Cycling takes about 15 seconds). ____
- Start video recorder. ____

- When data acquisition cycle light is illuminated turn arm switch on FS-17 firing system to "Arm" position and hold. ____

DURING THE OPERATION

FOR OPERATIONS CONTROLLED BY HIGH SPEED CAMERA

- When firing voltage reaches 3500, volts depress firing button. ____
- High Speed camera is activated, and when desired film speed is reached the camera triggers the detonator. ____
- Turn video recorder off. ____

STOPPING THE OPERATION

- Turn the handwheel counterclockwise until pressure on the deceleration gauge is indicated (monitor pressure not to exceed 1000 psi). ____
- Continue to decelerate until rotation of the arm has come to a complete stop (Centrifuge must not stop on position 6 or 12). ____
- Turn interlock switch key #3 to "OFF" position. ____
- Re-enter centrifuge and turn balance motor to "OFF" position. ____
- Connect Data Acquisition cable to trigger receptacle and download data. ____
- Ensure the centrifuge area is clean. ____

APPENDIX C

PLUVIATION PROCEDURE

To begin, it is important to note that the pluviator configuration is a function of soil type. Thus, substantial changes should be expected with a change in soil type. Minor changes should be sufficient for different densities within the same soil type. So, given the desired soil unit weight in lb/ft^3:

- Insert perforated plate of medium porosity.
- Ensure aluminum shutter plate is in full out position. This will misallign the holes between the shutter and porosity plates.
- Fill the transfer bucket with soil, connect to the hoist, lift and transfer soil into soil bin.
- Place payload bucket inside the plywood frame.
- Roll the pluviator frame over the payload bucket and lock into position by tightening the screws located at the bottom of each side ladder.
- The diffusers are an intragal part of the pulviator frame. In a two sieve system, the screen of the top sieve should be oriented 45 degrees from the direction of the bottom sieve.
- Push in the shutter plate to release the soil.
- Unlock the pluviator frame and roll it away to clear the payload bucket.
- Lift the payload bucket with the hoist, clear loose soil from edges of bucket and weigh.

ADJUSTMENT OF UNIT WEIGHT

PRIMARY ADJUSTMENTS:

- If the unit weight of soil is lower than desired change the "F" height by lowering the diffuser rack ($2'' = 0.3\ lb/ft^3$).

• If the unit weight of soil is higher than desired change the "F" height by raising the diffuser rack (2" = 0.3 lb/ft^3).

FINE ADJUSTMENT:

• Place a third sieve screen on top of the diffuser. Again, the direction of the screen should be offset from the direction of the screens already in the diffuser.

RAINING SOIL IN LEVEL LIFTS:

• Repeated tests have shown that a truly level soil placement is impossible. Velocities of the soil passing through the diffuser screens are somewhat random, and this produces a small slope of the soil surface. However, lowering the "H" height does cause a dramatic improvement on the levelness in the soil. In general, the lower the H" height (not to exceed below 12") the more nearly level the soil sample.

APPENDIX D

HIGH SPEED CAMERA FOOTAGE RATES VS TIME (1 THROUGH 10)

PHOTEC HIGH SPEED CAMERA

FILM FOOTAGE VS. TIME (2000 PICTURES/SEC)

ELAPSED TIME (ms)	ACCUMLATIVE FOOTAGE	PICTURES/SEC
600	11.995	1941
700	17.013	2007
800	22.046	2013
900	27.102	2022
1 SEC	32.182	2032
1.1	37.262	2032
1.2	42.342	2032
1.3	47.422	2032
1.4	52.500	2031
1.5	57.583	2033
1.6	62.663	2032
1.7	67.746	2033
1.8	72.824	2031
1.9	77.904	2032
2.0	82.980	2030
2.1	88.060	2032
2.2	93.142	2033

PHOTEC HIGH SPEED CAMERA

FILM FOOTAGE VS. TIME (2000 PICTURES/SEC)

ELAPSED TIME (ms)	ACCUMLATIVE FOOTAGE	PICTURES/SEC
2.4	103.306	2032
2.5	108.394	2035
2.6	113.482	2035
2.7	118.562	2032
2.8	123.648	2034
2.9	128.731	2033
3.0	133.816	2034
3.1	138.901	2034
3.2	143.989	2035
3.3	149.082	2037
3.4	154.167	2034
3.5	159.252	2034
3.6	164.337	2034
3.7	169.422	2034
3.8	174.510	2035
4.0	179.595	2034
4.1	184.685	2036
4.2	189.783	2039

PHOTEC HIGH SPEED CAMERA

FILM FOOTAGE VS. TIME (2000 PICTURES/SEC)

ELAPSED TIME (ms)	ACCUMLATIVE FOOTAGE	PICTURES/SEC
4.3	199.961	2035
4.4	205.051	2036
4.5	210.141	2036
4.6	215.231	2036
4.7	220.319	2035
4.8	225.409	2036
4.9	230.502	2037
5.0	235.592	2036
5.1	240.685	2037
5.2	245.778	2037
5.3	250.868	2036
5.4	255.963	2036
5.5	261.058	2038
5.6	266.158	2040
5.7	271.253	2038
5.8	276.351	2039
5.9	281.446	2037

PHOTEC HIGH SPEED CAMERA

FILM FOOTAGE VS. TIME (2000 PICTURES/SEC)

ELAPSED TIME (ms)	ACCUMLATIVE FOOTAGE	PICTURES/SEC
6.0	286.541	2038
6.1	291.634	2037
6.2	296.729	2038
6.3	301.822	2037
6.4	306.922	2040
6.5	312.017	2038
6.6	317.107	2036
6.7	322.185	2035
6.8	327.263	2031
6.9	332.338	2030
7.0	337.398	2024
7.1	342.461	2025
7.2	347.521	2024
7.3	352.591	2028
7.4	357.660	2026
7.5	362.720	2024
7.6	367.790	2028
7.7	372.860	2029

PHOTEC HIGH SPEED CAMERA

FILM FOOTAGE VS. TIME (3000 PICTURES/SEC)

ELAPSED TIME (ms)	ACCUMLATIVE FOOTAGE	PICTURES/SEC
900	30.540	3051
1 SEC	38.168	3051
1.1	45.771	3041
1.2	53.367	3038
1.3	60.953	3034
1.4	68.536	3033
1.5	76.112	3030
1.6	83.682	3028
1.7	91.250	3027
1.8	98.823	3029
1.9	106.396	3029
2.0	113.976	3032
2.1	121.552	3030
2.2	129.122	3028
2.3	136.700	3031
2.4	144.286	3034
2.5	151.864	3031

PHOTEC HIGH SPEED CAMERA

FILM FOOTAGE VS. TIME (3000 PICTURES/SEC)

ELAPSED TIME (ms)	ACCUMLATIVE FOOTAGE	PICTURES/SEC
2.6	159.444	3032
2.7	167.022	3031
2.8	174.599	3031
2.9	182.177	3033
3.0	189.760	3033
3.1	197.343	3028
3.2	204.919	3030
3.3	212.489	3028
3.4	220.070	3033
3.5	227.648	3031
3.6	235.231	3033
3.7	242.816	3032
3.8	250.389	3029
3.9	257.967	3031
4.0	265.543	3030
4.1	273.129	3034
4.2	280.722	3037
4.3	288.298	3030

PHOTEC HIGH SPEED CAMERA

FILM FOOTAGE VS. TIME (3000 PICTURES/SEC)

ELAPSED TIME (ms)	ACCUMLATIVE FOOTAGE	PICTURES/SEC
4.4	295.871	3029
4.5	303.444	3029
4.6	311.020	3030
4.7	318.593	3029
4.8	326.173	3032
4.9	333.753	3027
5.0	342.316	3025
5.7	348.874	3023
5.8	356.412	3015
5.9	363.942	3012
6.0	371.447	3002
6.1	378.940	2997
6.2	386.410	2988
6.3	TO END OF FILM	

PHOTEC HIGH SPEED CAMERA

FILM FOOTAGE VS. TIME (4000 PICTURES/SEC)

ELAPSED TIME (ms)	ACCUMLATIVE FOOTAGE	PICTURES/SEC
900	31.791	3707
1 SEC	42.099	4123
1.1	52.407	4161
1.2	62.810	4152
1.3	73.163	4141
1.4	83.496	4133
1.5	93.821	4130
1.6	104.134	4125
1.7	114.452	4127
1.8	124.760	4123
1.9	135.052	4120
2.0	145.345	4117
2.1	155.638	4117
2.2	165.938	4120
2.3	176.231	4117
2.4	186.519	4115
2.5	196.805	4114

PHOTEC HIGH SPEED CAMERA

FILM FOOTAGE VS. TIME (4000 PICTURES/SEC)

ELAPSED TIME (ms)	ACCUMLATIVE FOOTAGE	PICTURES/SEC
2.6	207.791	4117
2.7	217.378	4112
2.8	227.666	4115
2.9	237.942	4110
3.0	248.212	4108
3.1	258.487	4110
3.2	268.762	4110
3.3	279.012	4100
3.4	289.287	4110
3.5	299.542	4102
3.6	309.800	4103
3.7	320.058	4103
3.8	330.298	4096
3.9	340.538	4091
4.0	350.746	4083
4.1	360.939	4077
4.2	371.112	4069

PHOTEC HIGH SPEED CAMERA

FILM FOOTAGE VS. TIME (4000 PICTURES/SEC)

ELAPSED TIME (ms)	ACCUMLATIVE FOOTAGE	PICTURES/SEC
4.3	381.285	4052
4.4	391.355	4028
4.5	401.393	4015
4.6	411.393	4000
4.7	421.368	3996
4.8	431.343	3992
4.9	441.318	3990
5.0	451.293	3990

APPENDIX E

TDR APPLICATION

A. GENERAL

Use of the TDR requires knowledge of the computer keyboard function keys and their usage for the software. The following paragraphs describe the primary function keys and their usage in sequence. Finally a flowchart is provided to guide the user through a typical setup sequence of data recording.

B. CHANNEL SPECIFICATION (cF1)

A channel specification file is available for each channel in the Data Acquisition System. This takes advantage of the fact that the channels are configured in groups of similarly defined channels. By specifying a tag name and channel number, the record is saved to the hard disk and may be recalled by using the tag name. Whenever the Channel Specification is activated (cF1), the current working record is displayed. Of course, it is also possible to change tag names and channel numbers.

C. CHANNEL GROUP PROFILE (cF2)

The channel group profile monitor screen is used to govern the sample rates of each group of channels specified in the paragraph above. The group profile also controls internal trigger times and time delay for logic control modules. There are two logic modules, each of which controls a group of channels (8 channels each). Group 0 = channels 0 thru 7, and Group 1 = channels 8 thru 15.

D. SYSTEM CONTROL (cF4)

The user directs operation of the data acquisition system via keyboard commands. Control of arm, start, and trigger times, as well as calibration and channel balance of gauges are directed by the user at this time. Up to this point all setup information has been loaded onto a hard drive by the computer system. Information set up in the Channel Group Profile is now transferred to System Control in the on-board data acquisition system and stored. The auto sequence is checked for correctness and if errors are found the user uploads corrections via keyboard commands.

E. REAL TIME DISPLAY (cF7)

This screen allows the user to monitor instrumentation in real-time mode. Ten channels can be displayed at one time, with the ability to page through all channels being used. If a channel is not recording in real-time, the user must return to (cF4) System Control.

F. RECORD DATA (cF5)

The record data monitor screen is used to create, maintain, and download the data acquisition system. This screen allows the user to store data on hard drive, floppy, or other drive system. It automatically provides a record of test name, time and date on each recorded file.

G. GRAPHICS DISPLAY (cF8)

The graphics display is the most commonly used screen. It allows the user to display data in graphic form. A software package is integrated with the graphic display and provides the math and charting capability.

Programming the TDR correctly is essential for a succesful test. A flow chart (Fig 17) is provided to give the user a logical progression in setting up the TDR via the computer keyboard.

DATA ACQUISITION FLOW CHART FOR TDR

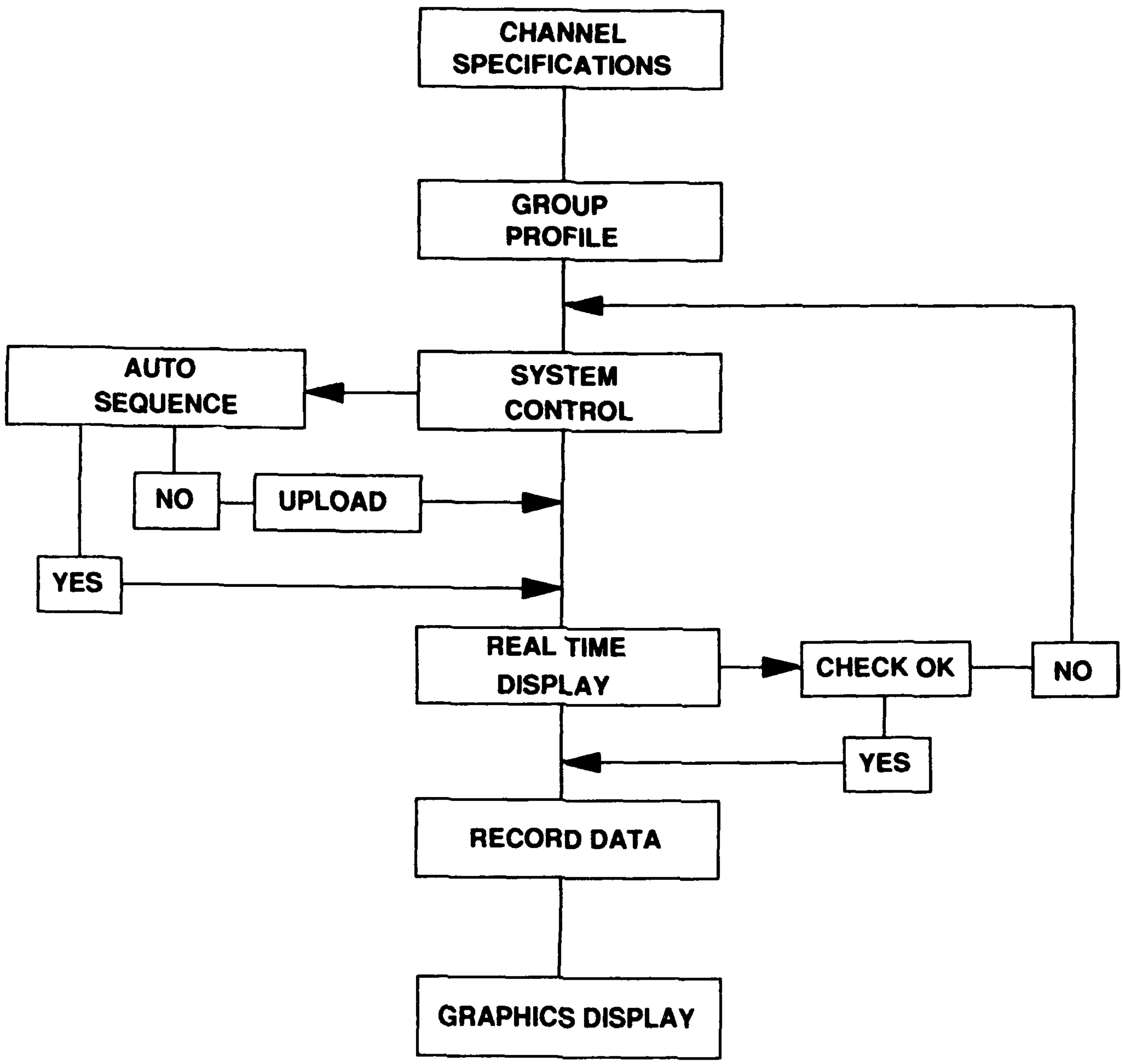

Figure E1. TDR FlowChart

REFERENCES

1. Thompson, P. Y. and Kim Y. S., "The development of a geotechnical centrifuge facility at Tyndall Air Force Base," Proceedings of the international conference on geotechnical centrifuge modelling, Paris, France, April 25-27, 1988, pp 67-72.

2. Genicso Incorporated, "Handbook of Operation, Service, and Maintenance Instructions for Model E185", Operations and Maintenance Manual, Genisco, Incorporated, Los Angelas, CA, 1958

3. Fragaszy, T. A. and Taylor T. A., Centrifuge Modeling of Projectile Penetration in Granular Soils, ESL-TR-88-76, Air Force Enineering and Services Center, Tyndall AFB, Fl, April 1989.

4. Kildalen, S. and Stenhamar P., NGI Laboratory Sand Rainer, Internal Report 51505-15, Norwegian Geotechnical Institute, February 1977.

5. Tabatabai, H. et.al., Centrifugal Modeling of Underground Structures Subjected to Blast Loading, ESL-TR-87-62, Air Force Engineering and Services Center, Tyndall AFB, Fl, March 1988.

6. Pacific Instruments, "Portable Data Acquisition System Model 5700," Operation and Maintenance Manual, Impact Publications, Monrovia, Ca, 1 March 1990

7. Walsh, A. "Centrifuge Modeling of Explosive-Induced Stress Waves in Unsaturated Sand," M.S. thesis, Colorado State University, Fort Collins, Colorado, 1992.

8. Hyde, D. W., ConWep (Conventional Weapons Effects), computer programs, USAEWES, 17 February 1988.

9. Baker, W. E., et. al., A Manual for the Prediction of Blast and Fragment Loading on Structure, Southwest Research Institute, San Antonio, TX, 738 pp., November 1980.